Low-Frequency Scattering from Heterogeneous Elastic Sea Beds

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LONG-TERM GOALS

The long term scientific objective of this research is to improve our understanding the physics and mechanisms of acoustic bottom interaction and reverberation, including acoustic penetration, propagation, attenuation and scattering in elastic sea beds at low and mid frequencies.

OBJECTIVES

The specific goal of this research is to develop a model of acoustic scattering due to volume heterogeneity consistent with existing propagation models in elastic layered sea beds and therefore to provide a self-consistent theoretical basis for improving and upgrading current bottom interaction codes (such as GABIM).

APPROACH

In many practical cases, description of acoustic propagation and reverberation in marine environment requires knowledge of two acoustic characteristics of the bottom: reflection loss and scattering strength. At present, GABIM (Geophysical Acoustic Bottom Interaction Model [1]) developed at APL-UW represents the most general code used for predicting and analysis of these characteristics for a wide variety of sea bed types. Note however that there are also cases where these two characteristics are not adequate descriptors, and therefore *alternative* approaches and models are needed.

Due to general sedimentation and stratification processes, bottom geoacoustic parameters are usually functions of depth (this way these parameters are normally documented in various existing sediment databases and models [2]). The main motivating idea and ultimate goal for development of GABIM is to provide practical possibility for modeling and prediction concurrently both reflection and scattering from seafloors with *arbitrary* stratification, so that these depth-dependent functions taken from the sediment data bases could be directly used for such predictions.

Development of the GABIM code is based on published results of basic research. However, the existing theoretical basis, presented in published literature, has not yet been developed adequately, and is unable yet to fulfill above-mentioned goals of GABIM. Particularly for this reason, GABIM has several drawbacks which significantly limit its practical capabilities. The main goal of this project is to improve and further develop the theoretical basis of GABIM using results of previous

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work: the elastic scattering model described in [3-5], a perturbation approach developed for scattering from continuous heterogeneity in layered fluid media [6-8], and discrete scattering work started in [9,10].

The volume scattering in elastic layers is by now the least developed part of existing models. In particular, no analytical expression for the scattering amplitude, or the T-matrix, has been yet developed for elastic layered heterogeneous media. Another drawback of existing models is related to using the "windowing" approximation resulting in simplified formulas for bottom scattering strength in the cases of uniform bottom half-space (fluid or elastic basement) and a layered fluid sediment [3,6,11]. This significantly limits accuracy of these calculations, particularly at steep grazing angles (in near-specular directions). One of objectives in this project is to remove such limitations and study in detail related effects.

One should note that the evaluation of T-matrix and the scattering strength for heterogeneous elastic medium, comparing to the fluid medium, requires much more extensive and time-consuming theoretical and mathematical analysis. This is somewhat related with additional channels of propagation and scattering due to elasticity of the bottom. In the elastic half-space case, adding the shear waves results in four scattering channels (compare with only one in the fluid case). Much more complications appear in the case of layered medium, even in the fluid case. This is related with additional scattering channels appearing due to both down- and up-going waves, and their possible combinations. Therefore, the development of practical approaches to simplify such calculations (or/and development of *alternative* approaches) is a critical component of this project.

WORK COMPLETED

A part of completed effort is a contribution to improve GABIM. It has provided a theoretical approach to take into account the "windowing effects" in a heterogeneous seafloor. At this stage of project, these effects were considered to modify models of volume scattering in an elastic half-space and in a fluid layer used in current version of GABIM [11]. The modified models were used in calculation of the bottom scattering strength [12] and are capable of improving two corresponding components of GABIM: the "sediment basement" component and the "sediment volume" component.

Another part of completed effort has included development of an *alternative* approach to describe scattering in a stratified marine environment which does not involve traditional acoustic characteristics: the bottom reflection loss and the bottom scattering strength. This approach significantly simplify accounting for the effect of stratification, using assumptions similar to described previously in [4] in a model of scattering from inhomogeneities in stratified sediments. The new approach is more general, so that it can be used in any part of marine environment, seabed or water column, with continuous or discrete heterogeneity.

A particular version of this new modeling approach was used to demonstrate its compatibility with GABIM. This version also has a primary application to analysis of bottom scattering, but includes the case of discrete scatterers (inclusions). By this reason it has been preliminary named GAMBID, Geo-Acoustic Model of Bottom Interaction and Discrete scattering [13]. This model can be considered as a supplement to GABIM, a recently published version of which treats only continuous heterogeneity of the sediment [11]. The GAMBID-model therefore is applicable to both types of scatterers, continuous and discrete, arbitrarily distributed in any part of stratified marine environment, seabed or water column.

RESULTS

The main results obtained at this stage of the project are reported in [12-15]. An improvement to GABIM was to remove the windowing approximation used in the anisotropic volume scattering approach, see [11]. This requires a numerical integration, and calculations have shown [12] that this modification, having generally only a modest effect on backscattering predictions, significantly alters bistatic predictions near the specular direction.

An *alternative* approach is described in [13] to model scattering in a stratified marine environment. It makes it possible to significantly simplify accounting for the effect of stratification. The simplicity results from assumption that the spectrum of heterogeneity is a smooth enough function, allowing neglecting bistatic scattering effects by ignoring difference in wave vectors appearing in the stratified environment with both down-going and up-going waves. It can be applied to any part of marine environment, e.g. heterogeneous sea-water column or near-sea-surface layer, where compressibility may fluctuate significantly due to spatial variations of bubble concentration. Also, it can be used for description of volume scattering due to randomly distributed discrete fluctuations of various kind.

In [13-15], a simple physics-based model, GAMBID, is presented, which provides a relationship between the scattering intensity and statistical characteristics of randomly distributed, either in water column or in the seabed, arbitrary sized and shaped discrete objects. This model is rather general and able to predict scattering in environment having arbitrary stratification. The scattering kernel is given by the local volume scattering coefficient, which is defined in two different ways. For continuous heterogeneity, it is defined by a spectral function of heterogeneity, and, for discrete scatterers, by their size/shape distributions. The model is applied to analysis of scattering from inclusions in stratified sand/mud sediments with shell inclusions, and model/data comparisons are presented.

IMPACT/APPLICATIONS

This research is to develop an adequate theoretical basis for direct improving of GABIM, Geophysical Acoustic Bottom Interaction Model, the most general code used for predicting and analysis of the bottom scattering strength and reflection loss for a wide variety of sea bed types. GABIM is planned for submission to OAML (Oceanographic and Atmospheric Master Library) and has been already widely used in the applied research and development community. In particular, it is one of the primary tools used in the Ocean Bottom Characterization Initiative (OBCI). The model of discrete scattering from inclusions in arbitrary stratified sediment developed in this research can be applied to upgrade GABIM.

RELATED PROJECTS

This project is built on results of previous work funded by ONR-OA [4,5,8-10]. It is closely related with ongoing work to upgrade GABIM [11] developed at APL-UW, which is widely used in the applied research and development community.

PUBLICATIONS

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